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Influence of Russian wheat aphid *Diuraphis noxia* feeding on grain yield components of barley and wheat in the forest-steppe of the Middle Volga region

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Abstract

Optimum temperature and plant growth conditions for the development of *Diuraphis noxia* (RWA) (Kurdjumov) (Rhynchota Aphididae) exist in spring barley. Our experiments showed that approximately 42% of barley tillers were damaged, compared to 6% of winter wheat tillers and 1% of spring wheat tillers. Relative resistance productive tillers infested with RWA to this pest was observed in hulled barley and acceptance in hulless winter and spring bread wheat. Awnless wheat was more resistant to RWA than awned wheat. The reduction of grain number and weight per spike, 1000-grain weight in productive tillers infested with of RWA was in winter wheat 48, 82 and 33%, spring wheat 55, 65 and 23%, in barley 23, 37 and 16%, respectively. Yield losses were estimated to 18.6% for barley, 5.9% for winter wheat and 0.7% for spring wheat.

Key words: damaged tillers, reduction of yield components, yield losses.

Introduction

Russian wheat aphid (RWA), *Diuraphis noxia* (Kurdjumov) (Rhynchota Aphididae) is currently distributed in most wheat producing countries around the world (North and South America; North Africa, Ethiopia, South Africa, Europe, Asia) except for Australia. Host plants of RWA include barley (*Hordeum vulgare*, *H. murinum*, *H. pusillum*); rye (*Secale cereale*); oat (*Avena sativa*); wheat (*Triticum aestivum*, *T. cylindricum*, *T. dicoccum*, *T. dicoccoides*, *T. durum*, *Triticum monococcum*, *T. tauschii*, *T. timopheevi*, *T. turgidum);* rice (*Oryza sativa*), triticale (*Triticum aestivum* × *Secale cereale*); canary grass (*Phalaris canariensis*); timothy grass (*Phleum pretense*); as well as cereals of the genera *Bromus*, *Elymus*, *Agropyron* (Armstrong *et al*., 1991; Hughes, 1988; Kindler and Springer, 1989; Stoetzel, 1987).

RWA causes leaf rolling, stunting of the host plant, chlorotic streaks, spike deformation, shrivelled grain and reduction of yield. Most RWA feed on the main stem, flag leaf sheath and developing kernels of bread wheat. There may be poorly formed or blank grains (Peairs, 1998). There are reports of RWA-related yield losses of 41-79% in barley, up to 86% in wheat in Ethiopia (Miller and Haile, 1988); 10-59% in barley in Mexico (Calhoum *et al.*, 1991); and 21-92% in wheat in South Africa (Du Toit and Walters, 1984; Hewitt, 1988). RWA severely reduced grain yield of canary grass (*Phalaris canadensis*) in the Konya province of Turkey, where grain losses of over 80% were reported by Uysal and Turanli (2004).

The main objectives of this study were compare estimations of the influence of RWA feeding on the basic components of grain productivity of barley, winter wheat and spring wheat (productive tiller number, tiller and spike length, grain number and weight per spike, thousand grain weight, yield loss) in the forest-steppe of the Middle Volga region and to examine how variety, cultivar, the morphological and phenological features of development influence plant resistance and acceptance of barley and wheat to RWA feeding.

Materials and methods

The studies were carried out on experimental fields of the Volga region Scientific Research Institute of Selection and Seed growing named after P. N. Konstantinov and at the Samara State Agricultural Academy in 2007, 2011 and mainly in 2014. The area of each experimental field was from 0.5 ha to 5 ha. The fields are situated on a landscape profile from a watershed to the bottom part of a slope. Length of a profile is about 8 km. The height of a watershed above the bottom part of a slope is about 12.2 m (40'). The soil is ordinary chernozem, clay loamy. The vegetative period 2014 was very dry in the last two thirds of May, first third of June and in July compared to the long-term means (table 1).

Varieties tested included two cultivars of feed barley (Povolzhsky 65, Kazak), one cultivar of malting spring barley (Povolzhsky 16) (*H. vulgare*) (variety *submedicum*), the bread spring wheat (*T. aestivum*) cultivars Kinelskaja Otrada, Kinelskaja Niva, Kinelskaja 2010, Kinelskaja 59 and Kinelskaja Jubilejnaja (variety *erythrospermum*) and the bread winter wheat cultivars Povolzhskaja 86, Kinelskaja 8 (variety *lutescens*), Konstantinovskaja (*erythrospermum*), Povolzhskaja Niva (*velutinum*) and Kinelskaja 4 (*albidum*). All cultivars were selected by the Volga region Scientific Research Institute of Selection and Seed growing (Glukhovtsev, 2014). All tested cultivars of barley are hulled, awned. Their lemma and palea adhere firmly to the seed and constitute the hull or husk. Seeds of *T. aestivum* are hulles or naked. When flowering, their lemmas and palaeas open to an angle of 20 to 35° (Mandy, 1970).

Table 1. Weather patterns during vegetative plant growth period 2014 at Ust-Kinelskij.

Month	10 day period	Average temperature (°C)		Total precipitation (mm)	
		Long-term average	2014	Long-term average	2014
April	Monthly average	4.6	5.6	27	23.7
May	I	12.0	12.8	10	13.3
May	II	14.1	21.8	11	0
May	III	15.9	20.8	12	7.4
May	Monthly average	14.0	18.5	33	20.7
June	I	17.7	22.2	13	0
June	II	18.7	16.4	13	41.9
June	III	19.7	18.4	13	2.3
June	Monthly average	18.7	19.0	39	44.2
July	I	20.4	23.2	15	3.5
July	II	20.8	20.3	16	0.7
July	III	20.9	18.2	16	1.2
July	Monthly average	20.7	20.5	47	5.4
August	Monthly average	18.9	21.4	44	24.0

Table 2. Influence of *D. noxia* on grain yield and yield components in spring barley (variety *submedicum*).

Components	Cultivars of barley, relief mesoforms					Mean	LSD (0.05)
	Povolzhsky 65		Kazak		Povolzhsky 16		
	watershed	bottom part of slope	middle part of slope	bottom part of slope	middle part of slope		
Productive tiller number (× m^2)	340 ± 29	505 ± 56	381 ± 49	536 ± 60	400 ± 45	432.4	22.7
Tiller number infested with RWA (%)	44.7 ± 0.8	39.7 ± 1.1	32.2 ± 0.9	42.6 ± 1.8	51.5 ± 4.3	42,1	4.8
Tiller length (cm): uninfested with RWA	64.9 ± 4,1	64.9 ± 10.8	62.8 ± 12.5	76.6 ± 3.6	53.6 ± 4.0	64.6	10.2
infested with RWA	45.4 ± 5.7	53.3 ± 4.3	54.5 ± 5.0	70.0 ± 1.6	45.1 ± 1.0	53.7	8.6
deviation (decrease) (%)	−30.0	−17.9	−13.2	−8.6	−15.9	−15.1	
Spike length (cm): uninfested with RWA	7.3 ± 0.8	6.6 ± 1.8	6.7 ± 1.0	7.2 ± 0.2	7.1 ± 0.4	7.0	0.5
infested with RWA	4.9 ± 0,8	5.3 ± 0.8	5.3 ± 0.5	6.1 ± 0.5	6.1 ± 0.5	5.5	1.4
deviation (%)	−32.9	−19.7	−20.9	−15.3	−14.1	−20.6	
Grain number per spike: uninfested with RWA	17.8 ± 2.4	15.4 ± 3.8	15.7 ± 2.7	18.7 ± 1.1	17.4 ± 1.8	17.0	*5.5*
infested with RWA	11.0 ± 1.7	11.7 ± 2.7	11.5 ± 1.8	14.7 ± 1.0	14.4 ± 0.8	12.7	*3.7*
deviation (%)	−38.2	−24.0	−26.8	−17.4	−17.1	−22.7	
Grain weight per spike (g): uninfested with RWA	0.71 ± 0.10	0.72 ± 0.12	0.63±0.09	0.72 ± 0.19	0.66 ± 0.12	0.69	*0.28*
infested with RWA	0.41 ± 0.04	0.48 ± 0.14	0.38 ± 0.06	0.41 ± 0.14	0.47 ± 0.06	0.43	*0.21*
deviation (%)	−42.3	−33.3	−39.7	−43.1	−28.8	−37.4	
Thousand grain weight (g): spikes uninfested with RWA	39.8 ± 0.6	45.7 ± 0.7	41.4 ± 0.7	40.4 ± 0.6	37.9 ± 0.7	41.0	1.4
infested with RWA	37.6 ± 3.6	40.4 ± 5.0	33.7 ± 4.8	28.2 ± 3.6	32.5 ± 3.8	34.5	9.1
deviation (%)	−5.5	−11.6	−18.6	−30.2	−14.2	−16.0	
Grain yield (c ha^{-1})	19.5 ± 1.6	29.6 ± 2.9	20.9 ± 1.7	32.1 ± 2.4	22.2 ± 2.1	24.9	4.7
Yield loss (c ha^{-1})	4.5	4.7	3.0	7.2	3.8	4.6	
%	23.1	15.9	14.4	22.4	17.2	18.6	

The cultivars of bread wheat variety *erythrospermum* (spring wheat, winter wheat Konstantinovskaja) tested are awned, their ears are comparatively friable. Other cultivars of a winter wheat are awnless, their ears more dense.

The main soil tillage included autumn ploughing to a depth of 20-22 cm. Fertilizers, pesticides and irrigation were not applied. Winter wheat was planted in the first third of September 2013, and spring wheat and barley were planted in the last third of April 2014. The seeding rate for wheat and barley was 4.5 million viable seeds per ha.

The numbers of uninfested and RWA-infested productive tillers per square meter were counted during the hard dough growth stage of wheat and barley in ten plots of 0.5 × 0.5 m in each test field. Tillers infested

Table 3. Influence of *D. noxia* on grain yield and yield components in spring wheat (variety *erythrospermum*).

Components	Cultivars of wheat, relief mesoforms									
	Kinelskaja Otrada		Kinelskaja Niva		Kinelskaja 2010		Kinelskaja 59	Kinelskaja Jubilejnaja		
	middle part of slope	bottom part of slope	watershed	middle part of slope	watershed	middle part of slope	middle part of slope	middle part of slope	Mean	LSD (0.05)
Productive tiller number (per m^{-2})	274.4 ± 25.3	300.1 ± 36.5	246.5 ± 23.4	352.5 ± 32.7	187.9 ± 15.4	312.3 ± 26.8	190.1 ± 18.5	333.4 ± 35.4	274.7	57.4
Tiller number infested with RWA (%)	2.62 ± 0.14	0.70 ± 0.06	0.65 ± 0.05	1.25 ± 0.11	0.85 ± 0.06	1.02 ± 0.08	0.68 ± 0.04	0.72 ± 0.05	1.06	0.17
Tiller length (cm): uninfested with RWA	70.6 ± 6.2	88.7 ± 7.5	90.7 ± 9.2	79.0 ± 5.8	74.7 ± 6.4	71.5 ± 7.6	92.7 ± 3.9	70.4 ± 6.8	79.8	14.1
infested with RWA	35.9 ± 4.1	57.9 ± 6.5	54.8 ± 7.2	44.0 ± 4.9	44.0 ± 5.3	39.5 ± 0.8	47.0 ± 4.8	44.6 ± 4.3	46.0	10.5
deviation (decrease) (%)	−49.2	−34.7	−39.6	−44.3	−41.1	−44.8	−49.4	−36.6	−42.5	
Spike length (cm): uninfested with RWA	5.7 ± 0.7	6.2 ± 0.5	5.0 ± 0.4	5.6 ± 0.5	5.2 ± 0.5	5.9 ± 0.4	6.7 ± 1.0	5.7 ± 0.6	5.8	1.2
infested with RWA	5.1 ± 0.4	5.8 ± 0.6	4.6 ± 0.5	5.0 ± 0.4	4.3 ± 0.7	4.3 ± 0.8	5.3 ± 0.9	4.7 ± 0.9	4.9	1.4
deviation (%)	−10.5	−6.5	−8.0	−10.7	−17.3	−27.1	−20.9	−17.5	−14.8	
Grain number per spike: uninfested with RWA	20.4 ± 2.5	28.3 ± 2.6	24.1 ± 3.0	18.4 ± 2.2	23.0 ± 2.1	20.7 ± 1.9	21.8 ± 2.8	20.8 ± 2.2	22.2	5.0
infested with RWA	10.8 ± 1.5	15.9 ± 1.8	14.2 ± 1.7	6.3 ± 1.0	10.5 ± 2.2	6.0 ± 0.7	8.0 ± 1.2	9.8 ± 1.6	10.2	3.2
deviation (%)	−47.1	−43.8	−41.1	−65.8	−54.3	−71.0	−63.3	−52.9	−54.9	
Grain weight per spike (g): uninfested with RWA	0.64 ± 0.06	1.02 ± 0.12	0.92 ± 0.14	0.57 ± 0.08	0.84 ± 0.09	0.72 ± 0.08	0.87 ± 0.10	0.66 ± 0.07	0.78	0.20
infested with RWA	0.2 8 ± 0.04	0.51 ± 0.06	0.41 ± 0.04	0.13 ± 0.02	0.32 ± 0.04	0.15 ± 0.02	0.22 ± 0.03	0.23 ± 0.03	0.28	0.07
deviation (%)	−56.3	−50.0	−55.4	−77.2	−61.9	−79.2	−74.7	−65.2	−65.0	
Thousand grain weight (g): spikes uninfested with RWA	31.4 ± 0.05	36.0 ± 0.06	40.4 ± 0.07	30.9 ± 0.05	31.2 ± 0.06	34.7 ± 0.04	39.9 ± 0.05	31.8 ± 0,03	34.5	0.11
infested with RWA	25.9 ± 0.06	31.2 ± 0.05	32.0 ± 0.06	20.5 ± 0.04	27.6 ± 0.05	25.0 ± 0.05	27.5 ± 0.04	23.4 ± 0.04	26.6	0.10
deviation (%)	−17.5	−13.3	−20.8	−33.7	−11.5	−28.0	−31.1	−26.4	−22.8	
Grain yield (c ha^{-1})	17.3 ± 1.5	30.5 ± 2.1	22.6 ± 1.8	19.9 ± 1.6	15.7 ± 1.4	22.3 ± 2.3	16.5 ± 1.8	21.9 ± 2.2	20.8	0.9
Yield loss (c ha^{-1})	0.26	0.11	0.08	0.19	0.08	0.19	0.04	0.10	0.13	
%	1.5	0.4	0.4	1.0	0.5	0.9	0.2	0.5	0.7	

with RWA easily differed from uninfested tillers, and showed tight rolling of flag leaves stunted tiller growth as well as the presence of aphids and signs of their feeding and development on the upper surfaces of curved leaves. All plants for laboratory analysis were collected in the grain ripening growth stage from four plots of 0.5 × 0.5 m from each field. All productive tillers were divided into uninfested and RWA-infested groups and the following measurements were made in the laboratory: number tillers per m^2, percentage of tillers infested with RWA, tiller and spike length (cm), number grains per spike, grain weight per spike (g), thousand grain weight (g), grain biological yield (c ha^{-1}), and percentage yield loss (c ha^{-1}) (tables 2-4). Yield data were adjusted to 14% moisture content. The data were processed using Microsoft Excel software, and least significant difference (LSD 0.5) was used to compare the mean ± standard deviation (SD) of each grain yield component for significance. Interrelations between percentage of tillers infested with RWA, grain yield components, and yield loss were estimated by linear correlation coefficients (r) and regression analysis (r is the coefficient of determination indicating closeness-of-fit of the regression).

Results

In hulled barley RWA feed on the inward of flag leaf sheath, main stem, rachis, glumes, lemma and palea, don't infest the developing kernel. In hulless bread wheat RWA also feed on the developing kernel. In barley an average reduction in the grain number per infested spike, grain weight per spike and thousand grain weight were 1.4-2.4 times less than in wheat.

The numbers of productive tillers infested with RWA varied from about 42% in barley, 6% in winter wheat and 1% in spring wheat. The highest percentages of infested productive tillers were in Povolzhsky 16 malting barley (51.5%) (table 2), Kinelskaja 8 winter wheat (16.1%) (table 4), and Kinelskaja Otrada spring wheat (2.6%) (table 3), all growing in the middle part of a slope. All yield components of wheat and barley were reduced by RWA feeding damage.

Tiller length was reduced by RWA feeding at infestation rates of 15.1, 37.4 and 42.5%, spike lengths were reduced by 20.6, 17.9 and 14.8%, in barley, winter wheat and spring wheat, respectively (tables 2-4). Spike length is a yield component that effects yield by changes in grain number per spike (Uysal and Turanli, 2004).

Table 4. Influence of *D. noxia* on grain yield and yield components in winter wheat. Variety *lutescens* cultivar Povolzhskaja 86 and Kinelskaja 8, variety *erythrospermum* cultivar Konstantinovskaja (Konst.), variety *velutinum* cultivar Povolzhskaja Niva (Povolz.), variety *albidum* cultivar Kinelskaja 4.

Components	Cultivars of wheat, relief mesoforms								
	Povolzhskaja 86			Kinelskaja 8	Konst.	Povolz.	Kinelskaja 4		
	middle part of slope	upper part of slope	watershed	middle part of slope	middle part of slope	middle part of slope	middle part of slope	Mean	LSD (0.05)
Productive tiller number (per m^{-2})	133.4 ± 15.2	166.6 ± 18.4	112.7 ± 10.6	116.8 ± 12.5	104.2 ± 14.6	115.5 ± 12.3	169.2 ± 19.7	131.2	31.5
Tiller number infested with RWA (%)	4.5 ± 0.4	4.1 ± 0.5	5.6 ± 0.6	16.1 ± 1.7	3.7 ± 0.4	2.9 ± 0.3	5.3 ± 0.7	5.9	1.7
Tiller length (cm): uninfested with RWA	82.6 ± 8.2	81.5 ± 6.0	79.6 ± 6.4	-	81.6 ± 7.7	86.6 ± 7.3	76.1 ± 5.8	81.3	14.7
infested with RWA	52.1 ± 6.1	57.9 ± 5.3	48.7 ± 2.9	-	46.7 ± 4.6	53,4 ± 5.8	53.8 ± 6.4	52.1	11.3
deviation (%)	−36.9	−29.0	−8.8	-	−42.8	−38.3	−38.3	−37.4	
Spike length (cm): uninfested with RWA	8.9 ± 1.2	7.7 ± 1.1	7.5 ± 0.8	-	9.0 ± 0.6	9.1 ± 1.0	8.8 ± 0.8	8.5	2.0
infested with RWA	7.6 ± 1.2	5.5 ± 1.1	5.7 ± 0.8	-	8.7 ± 1.1	7.4 ± 1.0	7.2 ± 1.3	7.0	2.3
deviation (decrease) (%)	−14.6	−28.6	−24.0	-	−3.3	−18.7	−18.2	−17.9	
Grain number per spike: uninfested with RWA	43.8 ± 3.9	35.2 ± 3.2	34.8 ± 4.0	37.2 ± 4.1	51.0 ± 3.9	50.2 ± 5.2	32.6 ± 3.6	40.7	8.5
infested with RWA	12.2 ± 3.1	12.7 ± 2.2	13.1 ± 1.8	8.5 ± 1.1	8.1 ± 0.9	12.0 ± 1.9	10.3 ± 1.6	11.0	4.1
deviation (%)	−72.2	−63.9	−62.4	−77.2	−84.1	−76.1	−68,4	−48,0	
Grain weight per spike (g): uninfested with RWA	2.01 ± 0.18	1.80 ± 0.16	1.62 ± 0.14	1.56 ± 0.16	2.7 ± 0.32	2.70 ± 0.41	1.20 ± 0.21	1.94	0.52
infested with RWA	0.33 ± 0.05	0.51 ± 0.07	0.41 ± 0.14	0.23 ± 0.05	0.30 ± 0.06	0.30 ± 0.04	0.20 ± 0.04	0.33	0.15
deviation (%)	−83.7	−71.7	−75.0	−85.3	−88.9	−88.9	−83.3	−82.4	
Thousand grain weight (g): spikes uninfested with RWA	45.7 ± 1.4	44.2 ± 1.2	42.0 ± 1.2	41.9 ± 1.0	45.6 ± 1.3	50.4 ± 1.3	37.8 ± 0.9	43.9	2.5
infested with RWA	24.3 ±2.1	25.8 ± 2.7	25.6 ± 2.6	27.1 ± 2.7	23.6 ± 1.9	25.6 ± 2.4	22.9 ± 2.3	25.0	5.1
deviation (%)	−46.9	−41.6	−39.0	−35.3	−48.2	−49.2	−39.4	−32.7	
Grain yield (c ha^{-1})	25.8 ± 2.0	29.1 ± 2.3	17.5 ± 1.6	15.7 ± 1.4	27.2 ± 2.5	30.4 ± 2.8	19.2 ± 1.6	23.6	4.4
Yield loss (c ha^{-1})	1.0	0.9	0.8	2.5	0.9	0.8	0.9	1.1	
%	3.9	3.1	4.6	15.9	3.3	2.6	4.7	5.4	

The grain number per infested spike was reduced by RWA feeding at the rate of about 23% in barley, 48% in winter wheat and 55% in spring wheat. Grain weight per spike was reduced by RWA feeding at the rate of 37, 82 and 65%, respectively (tables 2-4); this parameter showing the highest reduction rates due to RWA feeding. The mean 1000 grain weights were 16.0, 32.7 and 22.8% lower in RWA-infested tillers of barley, winter wheat and spring wheat, respectively, compared to uninfested tillers. In awned winter wheat the grain number per infested spike was reduced by an average of 79.0% in 2011 and 84.1% in 2014, grain weight per spike by 84.8 and 88.9 and thousand grain weight by 28.0 and 48.2%, respectively. In awnless winter wheat the average reductions of these yield components were 1.1-1.6 times less than in awned wheat (49.3, 65.2 and 24.5% in 2011; 71.7, 81.0 and 41.0% in 2014). The mean grain yield was 24.9, 23.6 and 20.8 c ha^{-1} in barley, winter wheat and spring wheat, respectively. Yield losses due to RWA infestation ranged from 14.4 to 23.1% in barley (table 2), 2.6-15.9% in winter wheat (table 4) and 0.2-1.5% in spring wheat (table 3). Yield losses due to RWA infestation in winter wheat Povolzhskaja 86 were 10.5% in 2007 and 3.9% in 2014.

Regression analysis between productive tiller number infested with RWA (%) and grain yield loss showed moderate positive degree in barley (r = 0.44). Closer correlation relationships between these factors have been found in spring and especially in winter wheat (r = 0.92 and 0.99, respectively).

Optimal regression equations obtained after stepwise regression analysis were polynomial equations: $y = -0.0512x^2 + 4.5202x - 8.867$ (spring barley); $y = -0.442x^2 + 2.0468x - 0.8296$ (spring bread wheat); and $y = 0.0106x^2 - 0.0792x + 1.0183$ (winter bread wheat), with coefficients of determination (R^2) = 0.60 (spring barley), 0.95 (spring bread wheat) and 0.99 (winter bread wheat), where y = % grain yield loss, x = % RWA infested tillers (figure 1).

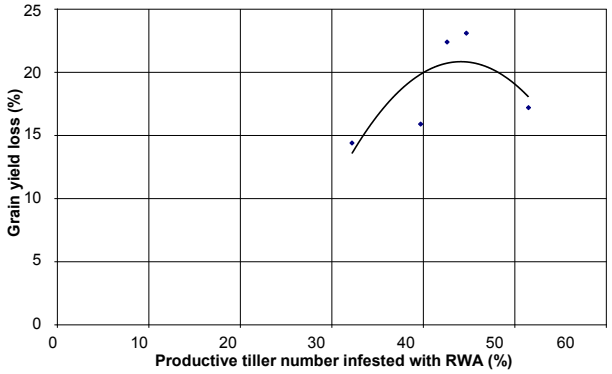
Discussion

Resistance to the RWA has been reported in many species of wheat, rye and barley, and 10 resistance genes have been identified (Souza, 1998; Kiplagat, 2005; Tolmay, 2006) that control different levels of resistance to different RWA biotypes (Burd *et al*., 2006, Tolmay *et al*., 2007). The RWA is quite cold-tolerant (Harvey and Martin, 1988), with the number of nymphs produced

Spring barley

$y = -0.0512x2 + 4.5202x - 8.867$

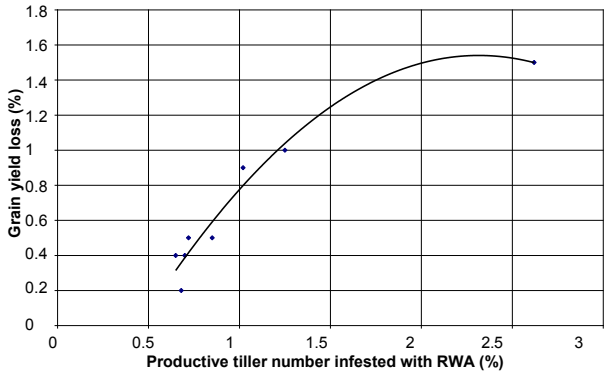
$R^2 = 0.5949$



Spring bread wheat

$y = -0.442x^2 + 2.0468x - 0.8296$

$R^2 = 0.9531$



Winter bread wheat

$y = 0.0106x^2 - 0.0792x + 1.0183$

$R^2 = 0.9848$

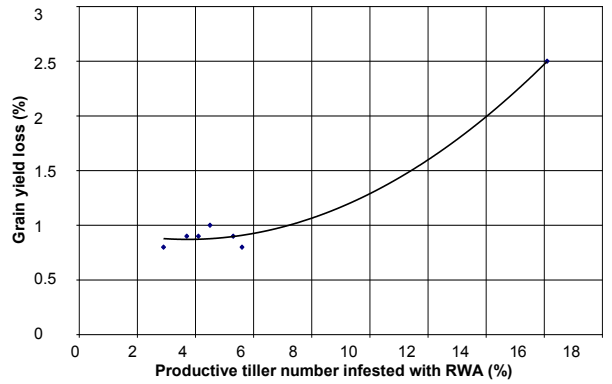


Figure 1. Grain yield losses in cereal crops due to *D. noxia* infestation.

increasing from 5 to 20 °C, and decreasing significantly from 20 to 30 °C (Ma and Bechinski, 2008). Reproduction is greatest at 18-21 °C on wheat in growth stages from stem elongation or jointing to heading (Behle and Michels, 1990). In forest-steppe of the Middle Volga region RWA is a monoecious species overwintering on winter wheat as holocyclic (eggs) clones. Newborn nymphs appear in the beginning of May during the tillering and stem elongation stages. They live openly, feed on the lower side of leaves, and form large colonies. When the fundatrices become adult, they crawl into leaf sheathes and live latently. Reproduction is greatest at 18-21 °C on wheat in growth stages from stem elongation to booting and heading (Behle and Michels, 1990). The leaves demonstrate a characteristic damage. RWA feeding causes leaf rolling, stunting in the host plant, chlorotic streaks, spike deformation, shriveled grain and reduction of yield. Growth of productive tillers infested with RWA is retarded and the heading stage can be absent. Most RWA feed on the main stem, flag leaf sheath and developing kernels of hulless bread wheat. In hulled barley RWA do not infest the developing kernel. The RWA feeds on winter wheat in spring, and migrate from winter wheat to spring barley and wheat in the end of May. Winged females appear in the second half of June, July and August, fly to winter wheat shoots in September.

In the forest-steppe of the Middle Volga region the booting and heading plant developmental stages are observed in winter wheat in the first half of May, then occurring in spring wheat and barley from June 5-20. The duration of booting and heading was 25-35 days for winter wheat cultivars, 15-25 days in spring wheat and 17-20 days for spring barley under the mean daily air temperature 10-15, 15-16 and 14-18 °C, respectively. RWA infested primary and secondary tillers in winter wheat and mainly secondary tillers developing from the base of primary tillers in barley and especially spring wheat. The number of productive tillers per plant was 3.2-5.2 in cultivars of winter wheat, 2.6-3.0 in barley and 1.2-1.5 in spring wheat. Plant density has an influence on the growth, microclimate and RWA populations occurring on each of the three hosts. Mean number of productive tillers per m^2 were 432 in barley, 275 in spring wheat and 132 in winter wheat. The optimum temperature and plant developmental stages present in spring barley for RWA development were reflected in the high % tiller damage (42.1%), compared to spring wheat (1.1%) and winter wheat (5.9%).

Productive tillers, relatively resistant to this pest infested with RWA to this pest were observed in hulled barley and acceptance in hulless winter and spring bread wheat. Awnless wheat was more resistant to RWA then awned wheat. The greatest reduction of yield components due the feeding of RWA was in winter wheat and the least in barley. RWA-related yield losses were estimated at 18.6% for barley, 5.9% for winter wheat and 0.7% for spring wheat. It is predominantly related to the number of productive tillers infested with RWA (r = 0.989).

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